Clearly Fuzzy

OMRON

Introduction

Fuzzy logic is attracting a great deal of attention in the industrial world and among the general public today. Quick to recognize this revolutionary control concept, OMRON seriously began to study fuzzy theory and technology in 1984, back when the term "fuzzy" was still relatively unknown.

Just three years later, OMRON stunned the academic world and triggered today's boom when it exhibited its first super-high-speed fuzzy controller. It was developed jointly with Assistant Professor Takeshi Yamakawa of Kumamoto University and shown at the Second International Conference of the International Fuzzy Systems Association (IFSA).

OMRON has since dedicated itself to exploring the potential of this innovative technology. The company invited Professor Lotfi A. Zadeh, the founder of fuzzy theory, to be a senior advisor, and welcomed researchers from China, a country known as one of the leaders in fuzzy-logic study. As a result of technological exchanges with research institutes of various countries, OMRON's fuzzy logic-related activities are reaching a global scale. Since 1984, OMRON has applied for a total of 700 patents, making the company an international leader in fuzzy-logic technology.

OMRON's enthusiasm for fuzzy logic stems from the company's goal of creating harmony between people and machinery. As a key technology in OMRON's future, we will be working hard to strengthen and refine this exciting technology and give it truly useful applications at production sites, in offices, in public facilities, as well as in everyday life.

We hope this booklet will be useful in increasing your knowledge, or at least in sparking your interest in this exciting technology.

OMRON Corporation

Truly Friendly Machines

Arrival of the Fuzzy Boom

The current fuzzy boom was triggered by the presentation of trial fuzzy applications at the Academic Conference of the International Fuzzy Systems Association (IFSA). The obvious feasibility of these forerunners of today's fuzzy logic deeply impressed conference attendees. Nowadays in Japan, fuzzy logic is successfully being applied to industrial systems such as elevators and subways and to an array of consumer electronic products. Convenient fuzzy-logic home electrical appliances include washing machines that sense the dirtiness and type of fabric to automatically determine water flow and detergent requirements; and vacuum cleaners capable of detecting not only the presence but the degree of dust on a floor!

Shades of Gray

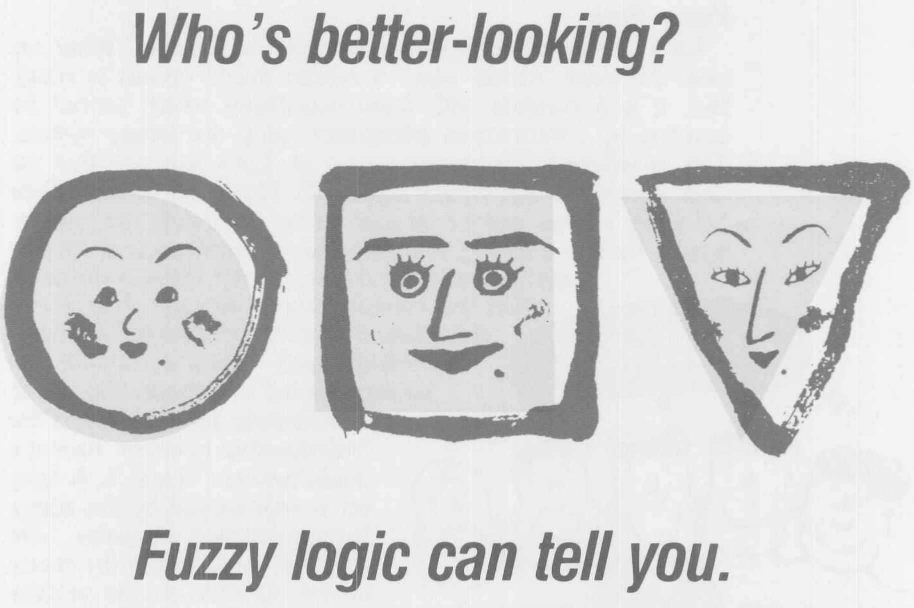
The theory of fuzzy logic was introduced to the world by Professor Lotfi A. Zadeh of the University of California at Berkeley. Professor Zadeh observed that conventional computer logic is incapable of manipulating data representing subjective or vague human ideas, such as "an attractive person" or "pretty hot." Computer logic previously envisioned reality only in such simple terms, as on or off, yes or no, and black or white. Fuzzy logic was designed to allow computers to determine valid distinctions among data with shades of gray, working similarly in essence to the processes which occur in human reasoning. Accordingly, fuzzy technologies are designed to incorporate fuzzy theories into modern control and data processing, to create more user-friendly systems and products.

A Warm Welcome in the Orient

Since fuzzy logic's world debut 26 years ago, theoretical and practical studies have been carried out in countries around the globe; fuzzy-logic research is currently underway in over 30 nations including the U.S.A., Europe, Japan and China. It may be surprising to some to note that the world's largest number of fuzzy-logic researchers are in China, with over 10,000 scientists and technicians presently hard at work. Japan ranks second in fuzzy-logic manpower, followed by Europe and the U.S.A. Among all nations however, Japan is currently positioned at the leading edge of fuzzy-logic application studies. So it may be that the popularity of fuzzy logic in the Orient reflects the fact that Oriental thinking more easily accepts the concept of "fuzziness."

Fuzzy—Part of Every Day at OMRON

OMRON is also hard at work in the fuzzy-logic field. Projects currently on the go at OMRON include working to establish a fuzzy technological base, developing new products incorporating fuzzy theory, adapting fuzzy-logic technology to existing products and conducting seminars for interested audiences from outside OMRON. Fuzzy logic has in fact grown to such proportions that it has become an integral part of the new corporate culture at OMRON.



"Fuzzy" Made Clear

What is "Fuzzy?"

Originally stemming from the fuzz which covers baby chicks, the term "fuzzy" in English means "indistinct, blurred, not sharply delineated or focused." This term is "flou" in French and pronounced "aimai" in Japanese. In the academic and technological worlds, "fuzzy" is a technical term. Fuzziness in this sense represents ambiguity or vagueness based on human intuitions rather than being based on probability. Twenty six years ago, Professor Lotfi A. Zadeh introduced "fuzzy sets" to adapt the concepts of fuzzy boundaries to science. Fuzzy theory was devised around the fuzzy sets and a new field of engineering known as "fuzzy engineering" was born. Although "fuzzy sets" may sound very mathematical, the basic concept can be explained simply.

How Fuzzy Theory Works

Fuzzy Sets

Let's take an example of the concept "middle age." When we hear the term "middle age," a certain image comes to mind. But, it is a concept with fuzzy boundaries which cannot be handled by conventional computers using the binary system. This is where fuzzy theory comes in. Let's suppose that we have concluded that middle age is 45. However, people 35 or 55 years of age cannot be said to be "definitely not middle-aged." There is a feeling, however, that the implication of "middle age" is somewhat different inside those boundaries. On the contrary, those younger than 30 or older than 60 can be considered "definitely not middle-aged." Such a concept can be represented in a graph (Fig. 1), or a characteristic function called the "membership function" having a grade between 0 and 1. A fuzzy set is represented by this membership function. However, note that the grade within the membership function can be continuously varied between 0 and 1. This makes possible the quantitative representation of an abstract intention.

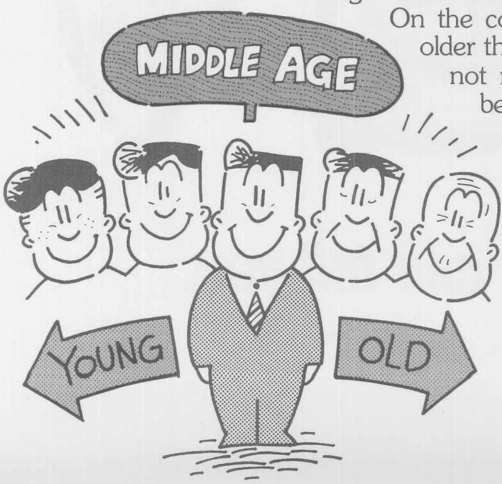
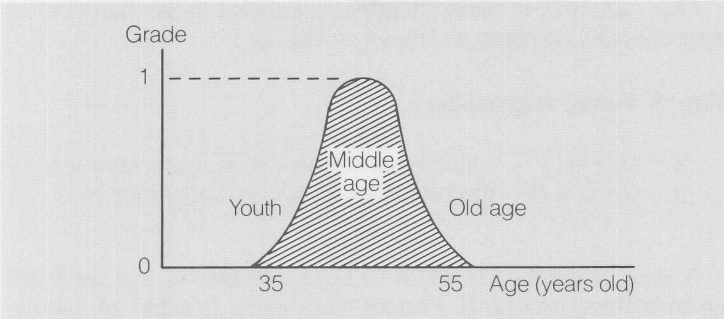


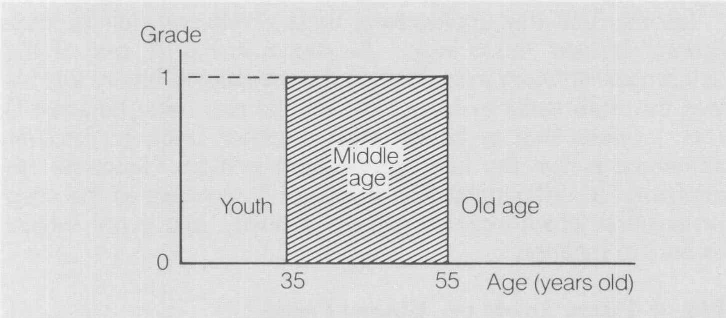
Fig. 1 Fuzzy Sets



Crisp Sets

In contrast, the binary system employed in conventional computers works by first specifying a fixed range, so that "middle age" represents the age range from 35 to 55 years old. This is represented by the graph shown in Fig. 2.

Fig. 2 Crisp Sets



According to this graph, people who are 34 and 56 years old are not "middle-aged." Unfortunately, someone who is now considered young at 34 will suddenly enter middle age as soon as their next birthday arrives! This sort of unnaturalness is due to inflexible value assignments. Such concepts with distinct values of 0 or 1 are called "crisp sets" as opposed to the "fuzzy sets."

Fuzzy Theory in Action

Fuzzy Algorithm

One example of fuzzy theory applications is the handling of approximate numbers as shown in Fig. 3.

Fig. 3 Fuzzy Algorithm

$\underline{2} + \underline{6} = \underline{8}$
$\underline{2} \times \underline{6} - \underline{4} = \underline{8}$

(Underlined numbers show fuzzy numbers, meaning they are approximate values.)

If approximately 2 is added to approximately 6, the result will be something around 8. People often make this sort of calculation. For instance, we frequently estimate the result when performing a calculation such as "118 + 204." We would say that adding a number slightly over 100 to another slightly over 200 equals a number slightly greater than 300. This sort of calculation comes easily to human beings but cannot be so well handled by conventional computers, which must have crisp data with which to work.

The Logic in Fuzzy Logic

Another field that applies fuzzy theory concerns artificial intelligence, termed "fuzzy logic." As shown in Fig. 4, one of the differences between fuzzy logic and conventional binary logic is that the truth value in fuzzy logic can be any value between 0 and 1, while that in binary logic is either 0 or 1. Another difference is that the fuzzy proposition includes "fuzziness" as expressed in ordinary spoken language, in contrast to the crisp proposition which must be defined distinctly, and is not subject to human intuition.

Fig. 4 Fuzzy Logic vs. Binary Logic

<u>Fuzzy logic</u>
"It is very cloudy today."
"It is cloudy today." — "Nearly true"
Fuzzy proposition — Fuzzy truth value (0 - 1)

<u>Binary logic</u>
"Earth is a planet."
"Earth is a planet." — "True"
Crisp proposition — (0 or 1)

Common Sense Fuzzy

"Fuzzy inference" is a reasoning method using fuzzy theory, whereby human knowledge is expressed using linguistic rules ("If A is B, then C is D") with variables B and D. As shown in Fig. 5 (2), fuzzy inference is also called "daily inference" or "common sense inference" since it is performed by ordinary people. However, conventional computers that employ binary logic cannot handle this reasoning. The use of fuzzy theory enables the development of an expert system that can handle sophisticated knowledge and rich human experience through direct programming in an almost natural language.

Binary logic-based inference is possible only when data coincides exactly with the premise input. On the other hand, fuzzy inference is possible even when the meaning of the fact differs slightly from the given knowledge. Drawing a conclusion like "Add a little cold water," fuzzy inference matches the conclusion based on human experience, intuition, or possibly even reality.

The "knowledge" part of fuzzy inference has the structure "if A is B, then C is D." In the example shown in Fig. 5 (2), the concepts of "very hot" and "plenty of cold water" are subjective and thus represented by fuzzy sets.

As you may know, fuzzy theory was devised for the purpose of enabling machines to handle subjective human ideas and operate based on advanced knowledge as well as applications of human beings' intricate experiences. In other words, fuzzy theory allows for the development of truly user-friendly machines.

Fig. 5 Comparison of Inference Methods

(1) Binary logic inference
(Syllogism: A is B; B is C; therefore A is C)

Premise 1:	Socrates is human.
Premise 2:	All humans are mortal.
Conclusion:	Socrates is mortal.

(2) Fuzzy inference

Knowledge:	If the water is very hot, add plenty of cold water.
Fact:	The water is moderately hot.
Conclusion:	Add a little cold water.

An Invitation to Fuzzy Control

The Mechanism: Fuzzy Inference Control

We can examine fuzzy control by using the example of controlling an automobile. Fig. 6 shows the hypothetical conditions that would be subject to fuzzy inference control. The mechanism is outlined in Fig. 7.

Fig. 6 Hypothetical Case of Driving

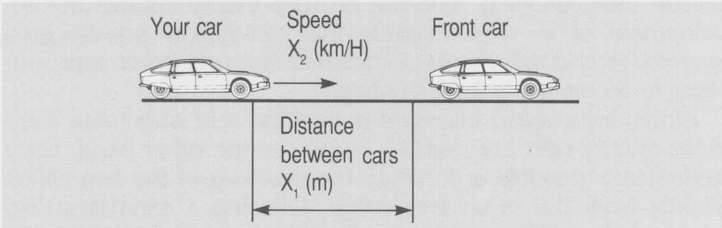
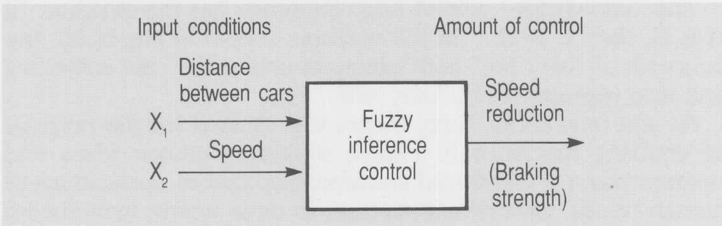


Fig. 7 Control Mechanism

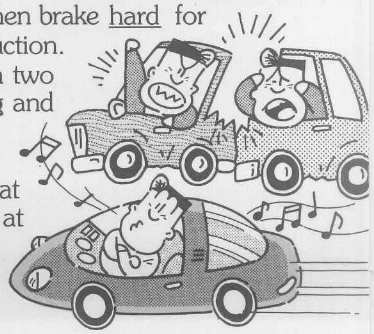


(1) Express experience and expertise in the form of rules.

With fuzzy inference control, these rules are called "production rules." They are represented in the form of "If X is A, then Y is B." To put it more simply, let's consider two rules as follows:

Rule 1: If the distance between two cars is <u>short</u> and the car speed is <u>high</u>, then brake <u>hard</u> for substantial speed reduction.

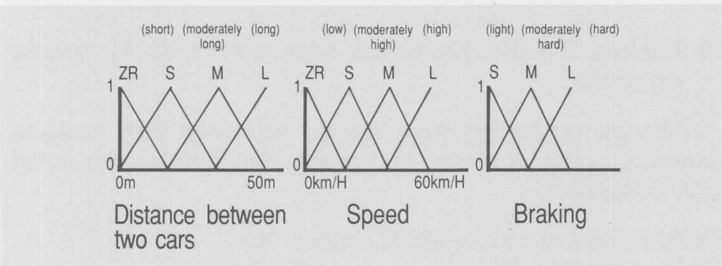
Rule 2: If the distance between two cars is <u>moderately long</u> and the car speed is <u>high</u>, brake <u>moderately hard</u> (under the condition that the front car is moving at a constant speed).



(2) Determine membership functions for the antecedent and consequent parts.

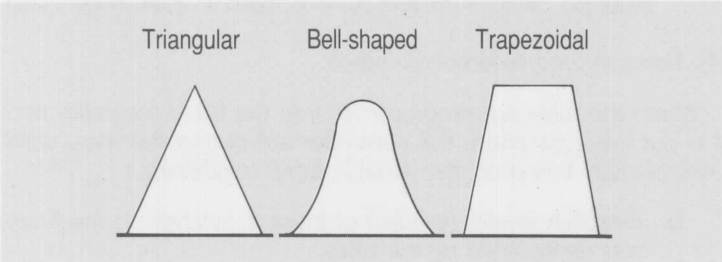
The distance between the two cars and the car speed (antecedent parts) and the level of speed reduction, or braking strength (consequent part), are not numeric values but are represented by "fuzzy sets" expressed through linguistic rules. The distance between the two cars and the speed have a multiple number of fuzzy values and are therefore called "fuzzy variables." Hence, values (labels) of these fuzzy variables and the shapes of membership functions can be determined, as shown in Fig. 8.

Fig. 8 Determination of Membership Functions



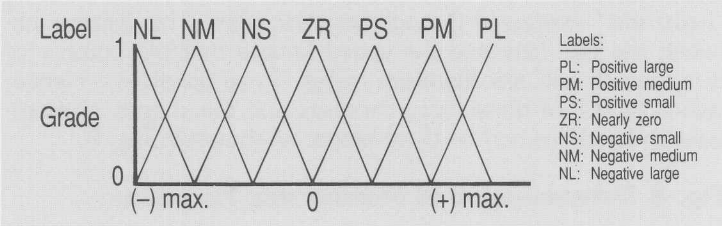
Membership functions (fuzzy variables) can take three different shapes (Fig. 9):

Fig. 9 Membership Function Shapes



The shapes differ depending upon the characteristics of the machine to be controlled. Normally, there are three (large, medium, small), five (high, moderately high, normal, moderately low, low), or seven (large, medium and small both in positive and negative directions, centering around approximately 0) labels (Fig. 10). Many fuzzy controllers use seven labels, as in the OMRON FZ-3000 fuzzy controller, for example.

Fig. 10 An Example of Triangular Fuzzy Variables



(3) Replace linguistic production rules with codes for simpler expression.

Although production rules can be expressed with everyday language, codes are used to simplify the input to the actual fuzzy controllers.

(Distance between two cars: X_1; speed: X_2)
(Braking strength: Y)
(Labels — small, medium, large: S, M, L)

Let's express the above rules using these codes.

Rule 1: If X_1 = S and X_2 = M, then Y = L. (Fig. 11-1)

Rule 2: If X_1 = M and X_2 = L, then Y = M. (Fig. 11-2)

(4) Execute fuzzy inference control.

When the rules are programmed into the fuzzy controller and it is put into operation, the controller will output the most valid control value based on the variable input conditions.

1) Establish grades (validity) of input in relation to the fuzzy sets determined by the rules.

As for the fuzzy set (S: short distance) determined by rule 1, the grade (g_{11}) of the input distance "30m" is 0.4. Similarly, the grade (g_{12}) of the input speed "40km/H" is 0.2 according to the fuzzy set (M: moderately high speed). As for rule 2, grades (g_{21}) and (g_{22}) can be determined as 0.7 and 0.6, respectively.

2) Determine the grade of each antecedent part.

The grade of antecedent parts can be determined by selecting the smaller value of the grades of inputs. This process is called "determining MIN (minimum)."

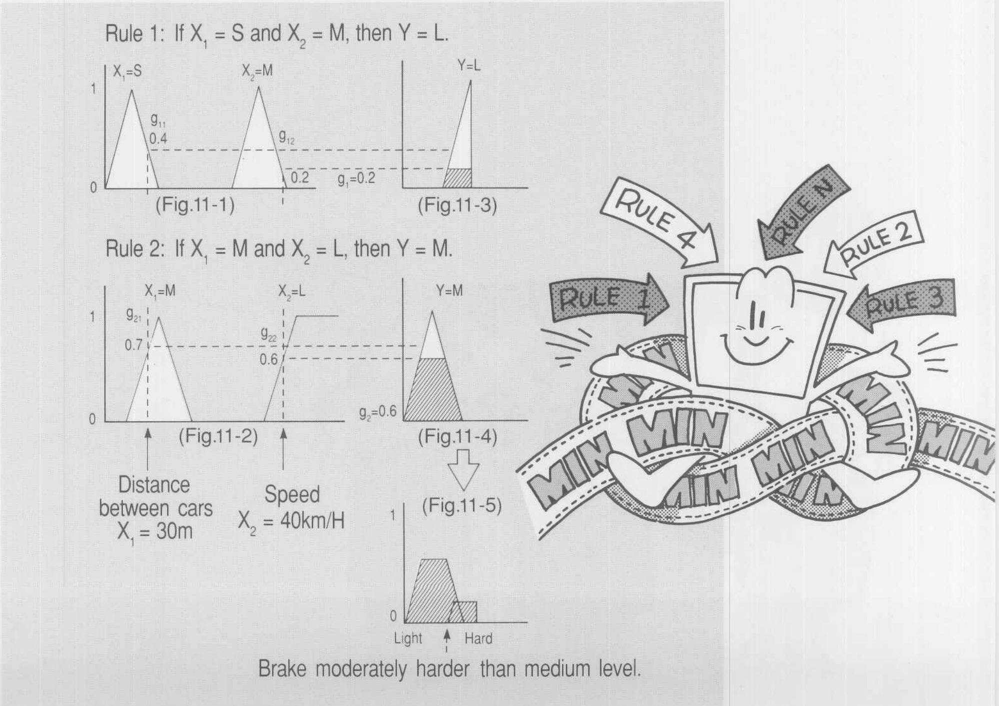
Rule 1: As $g_{11} = 0.4$ and $g_{12} = 0.2$, the grade (MIN value) of antecedent part $(g_1) = 0.2$

Rule 2: As $g_{21} = 0.7$ and $g_{22} = 0.6$, the grade (MIN value) of antecedent part $(g_2) = 0.6$.

3) Adjust the membership function of the consequent part.

The consequent part of rule 1 is fuzzy set (L) representing hard braking, while that of rule 2 is fuzzy set (M) representing medium (moderately hard) braking. The grades (amplitudes) of these fuzzy membership functions are then adjusted to match the grades of their respective antecedent parts. As a result, the consequent parts of rules 1 and 2 are respectively shaped as shown by the diagonal lines in Figs. 11-3 and 11-4.

Fig. 11 Fuzzy Inference



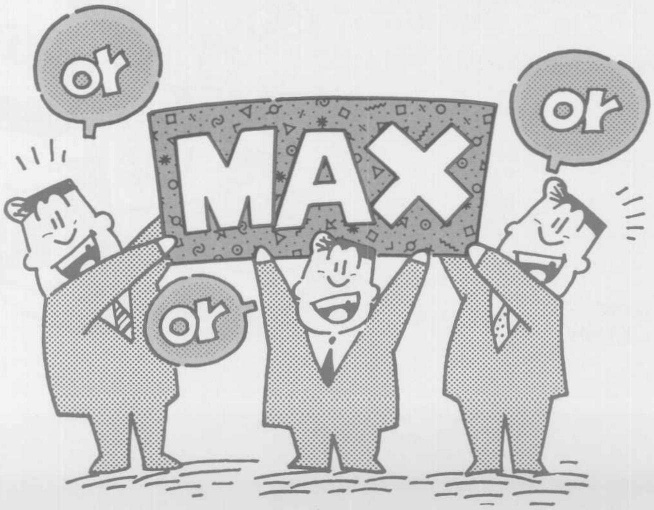
4) Total evaluation of conclusions based on these rules (determination of control amounts).

When the conclusions are derived through inference based on each of these rules (adjusted fuzzy sets of the consequent parts), the final conclusion is then determined by summing the fuzzy sets of the conclusions for each rule. This process is called "determining MAX (maximum)."

Fig. 11-5 shows the membership function (fuzzy sets) of the final conclusion. No control can be performed since the control amount (braking strength) has a wide range from hard to light. To determine the control amount at a certain point, the summed area of the fuzzy sets is divided in two. In other words, the center of gravity is determined. In this case, the center of gravity is located at a position moderately harder than medium strength, as indicated by the arrow. (Fig. 11-5)

This process considers several variable factors, and is thus very similar to the human thinking process.

With fuzzy control, steps (1) through (4) are performed continuously. In contrast, with information processing, these procedures are only executed each time the input data varies.



The Advantages of Fuzzy Inference Control

Parallel Control

Conventional control based on modern scientific analysis determines the control amount in relation to a number of data inputs using a single set of equations to express the entire control process. Expressing human experience in the form of a mathematical formula is very difficult, perhaps impossible. In contrast, fuzzy inference control has the following advantages over conventional control:

1) Expression of control is easy as it need only derive localized control rules for each location (or event) in the control range.
2) It therefore handles complex input/output by using many control rules, each of which is effective over a specific location.
3) Operations can be conducted in parallel (or simultaneously) within fuzzy inference by executing various rules. This results in speedy operation, regardless of the total number of rules.

Logical Control

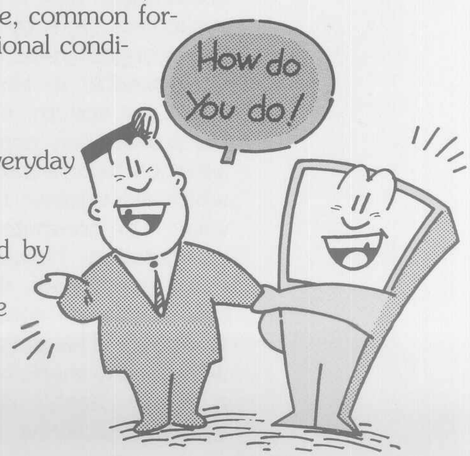
Fuzzy inference control rules are expressed logically using simple linguistic rules ("If A is B, then C is D"). Because everyday language can be used, fuzzy inference control proves ideal for expressing the sophisticated knowledge of experts and incorporating valuable intuition (or a "sixth sense").

1) Multiple conditions can be included as the antecedent part of the rules.
(e.g. If $X_1 = A$, $X_2 = B$ and $X_3 = C$, then $Y = D$)
2) Rules can be expressed with a single, common format regardless of normal or exceptional conditions.

Linguistic Control

Fuzzy rules can be expressed using everyday language, giving the following advantages:

1) Fuzzy control is easy to understand by the machine operator or others.
2) The operator can easily interpret the effect or outcome of each rule.



Growing Up: Fuzzy Technology Catches On

The Birth and Evolution of Fuzzy

Fuzzy logic was born only 26 years ago when Professor Lotfi A. Zadeh submitted a paper entitled “Fuzzy Sets” to the science magazine *Information and Control*. In that paper, he labeled sets with unclear boundaries "fuzzy sets," such as attractive people, tall people, and large numbers. According to Dr. Zadeh, the fuzzy set plays an important role in pattern recognition, interpretation of meaning, and especially abstraction, the essence of the thinking process of the human being.

Is “Fuzziness” Really Better?

Dr. Zadeh was one of the original founders of the modern control theory and remains an authority in this field. Modern control theory is exact, precise, and logical, harboring no hint of "fuzziness."

Today, however, the subjects of control have become increasingly larger in scale, in turn requiring more advanced and complex control systems, like those used to control robots and rockets. You need a tremendous amount of power if you want to use a computer to execute such complicated control using modern theory. Precise programming is needed for every instruction and every piece of data to put the computer into operation. It also takes an extremely long time to execute the programs. Dr. Zadeh devised fuzzy theory to overcome these debilitating limitations of modern theory.

There was also another, probably more important factor that encouraged him to come up with a new idea. Conventional computers work by identifying the factor which seems to have the strongest influence on the systems to be controlled, since it is impossible to simultaneously command all the factors that affect the system. In other words, the computer assumes that the system only consists of those selected items. Moreover, all assumed factors must be described digitally. So for some items which are unclear, the computer simply assigns an appropriate value. The computer is, of course, capable of accurate and fast computation. However, as the conditional parameters include many hypotheses, the computer may sometimes yield a ridiculous conclusion contrary to what common sense would lead us to expect. This is caused by its attempts to replace "fuzziness" with fixed numeric values. Thus, it became necessary to develop a theory capable of dealing with the vagueness prevalent in everyday decisions.

Strong Opposition

Even though Dr. Zadeh's theory is now quite popular and quoted in a large number of academic papers, it had to endure skepticism and hostility from U.S. researchers and academics in its early days. Some American mathematicians scoffed at the theory, saying that "fuzziness" could be represented using conventional mathematics. Once a noted authority in modern theory, Dr. Zadeh's ready acceptance of "fuzziness" was considered to be a frivolous escape from his own beliefs, and many criticized him for not fulfilling his duty as a scientist.

A Profile of Professor Zadeh

You may want to know a little about the Professor. Here is a very brief profile:

Lotfi A. Zadeh was born in Iran on February 4, 1921. In 1956, he was a visiting member of the Institute for Advanced Study in Princeton, New Jersey and held numerous distinguished visiting appointments around the U.S. In 1959 he joined the University of California's Electrical Engineering Department at Berkeley, and served as its chairman from 1963 to 1968.

Before 1965, Dr. Zadeh's work focused on system theory and decision analysis. Since then his interests have shifted to the theory of fuzzy sets, and its applications.

Zadeh attended the University of Teheran, MIT, and Columbia University, and is a fellow of the IEEE and AAAS. He is also a member of the National Academy of Engineering. Now, Dr. Zadeh is a senior advisor to OMRON Corporation.

A Motivating Debate

Here is a little story about how fuzzy logic was invented. One day, Dr. Zadeh got into a long argument with a friend about who was more beautiful, his wife or his friend's. Each thought his own wife was more beautiful than the other's wife. There is, of course, no objective way to measure beauty. The concept of "beautiful" greatly differs among people. Although they continued the argument for a long time, they could not arrive at a satisfactory conclusion. This argument triggered Dr. Zadeh's desire to express concepts with such fuzzy boundaries numerically, and he thereby devised fuzzy sets. Thus goes the legend.

From Industry to Consumer

The first applications of fuzzy theory were primarily industrial, such as process control for cement kilns. Then, in 1987, the first fuzzy logic-controlled subway was opened in Sendai in northern Japan. There, fuzzy-logic controllers make subway journeys more comfortable with smooth braking and acceleration. In fact, all the driver has to do is push the start button! Fuzzy logic was also put to work in elevators to reduce waiting time. Since then, the applications of fuzzy-logic technology have virtually exploded, affecting things we use every day.

Major Areas of Fuzzy Research and Applications

Field	Major Applications
Automation	Steel/iron manufacturing, water purification, manufacturing lines and robots, train/elevator operation control, consumer products, etc.
Instrumentation and analysis	Sensors, measuring instruments, voice/character recognition, etc.
Design/judgement	Investment/development consultation, train scheduling, system development tools, trouble-shooting, etc.
Computers	Operators, arithmetic units, microcomputers, industrial calibrators, etc.
Information processing	Database, information retrieval, system modelling and mathematical programming, etc.

Historically Speaking...

The year 1990 witnessed the 25th anniversary of the invention of fuzzy theory. It has undergone numerous transformations since its inception with a variety of fuzzy–logic applications emerging in many industrial areas. Dividing these past years into different stages, the early 1970s are the "theoretical study" stage, the period from the late 1970s to early 1980s the stage of "developing applications for control," and that from late 1980s to the present the stage of "expanding practical applications."

Here are the major events in the history of fuzzy logic:

1965: Professor L.A. Zadeh of the University of California at Berkeley introduces "fuzzy sets" theory.

1968: Zadeh presents "fuzzy algorithm."

1972: Japan Fuzzy Systems Research Foundation founded (later becoming the Japan Office of the International Fuzzy Systems Association (IFSA)).

1973: Zadeh introduces a methodology for describing systems using language that incorporates fuzziness.

1974: Dr. Mamdani of the University of London, U.K. succeeds with an experimental fuzzy control for a steam engine.

1980: F. L. Smidth & Co. A/S, Denmark, implements fuzzy theory in cement kiln control (the world's first practical implementation of fuzzy theory).

1983: Fuji Electric Co., Ltd. implements fuzzy theory in the control of chemical injection for water purification plants (Japan's first).

1984: International Fuzzy Systems Association (IFSA) founded.

1985: 1st IFSA International Conference.

1987: 2nd IFSA International Conference. (Exhibit of OMRON's fuzzy controller, a joint development with Assistant Professor Yamakawa.)

Fuzzy logic-controlled subway system starts operation in Sendai, Japan.

1988: International Workshop on applications of fuzzy logic-based systems (with eight fuzzy models on display).

1989: The Laboratory for International Fuzzy Engineering Research (LIFE) established as a joint affair between the Japanese Government, academic institutes and private concerns.

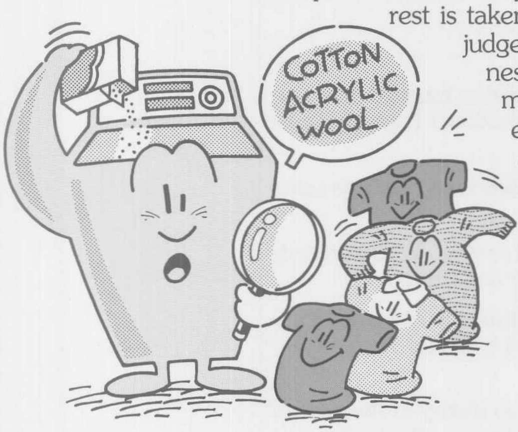
Japan Society for Fuzzy Theory and Systems founded.

A Fuzzy Future

Fuzzy Fever Hits Japan

1987 marked the start of Japan's so-called "fuzzy boom," reaching a peak in 1990. A wide variety of new consumer products since then have included the word "fuzzy" on their labels and have been advertised as offering the ultimate in convenience.

For instance, fuzzy logic found its way into the electronic fuel injection controls and automatic cruise control systems of cars, making complex controls more efficient and easier to use. The "fuzzy" washing machine has more than 400 preprogrammed cycles; yet despite this technological intricacy, operation is very simple. The user only needs to press the start button and the rest is taken care of by the machine. It automatically judges the material, the volume and the dirtiness of the laundry and chooses the optimum cycle and water flow. In air conditioners, fuzzy logic saves energy because it starts cooling more strongly only when a sensor detects people in the room.



We could go on and on with examples of camcorders, television sets, and even fund management systems. The sweeping popularity of fuzzy logic in Japan might even surprise Dr. Zadeh, its founder.

No Limits: Promise for the Future

Just from these few examples, it is clear that fuzzy logic encompasses an amazing array of applications. Fuzzy logic can appear almost anyplace where computers and modern control theory are overly precise; as well as in tasks requiring delicate human intuition and experience-based knowledge. Now that your mind is open to fuzzy thinking, here are some unique ideas applying fuzzy logic.

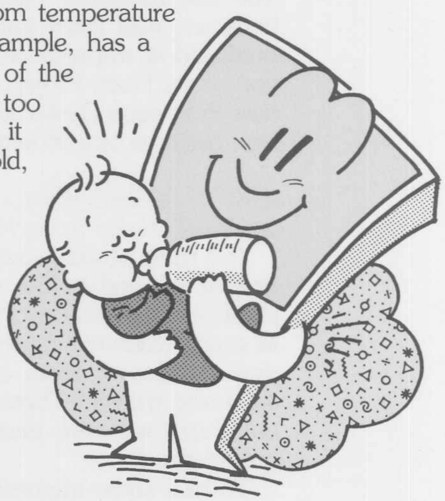
"Fuzzy" Child Care Expert System

Here is an idea a 24-year-old housewife developed from her experience in raising children. It may seem obvious that babies don't drink the way it is described in child care books. They may drink a little or a lot depending on their physical condition, mood, and other factors. She conceived a fuzzy-logic program that would recommend how much to feed the baby. The program determines the appropriate amount of milk according to a knowledge base that includes the child's personality, physical condition, and some environmental factors. Although adapting fuzzy logic to babies may seem silly, one can easily imagine using it to control the feeding of animals in captivity, for instance.

Fuzzy is for Everyone

Many ideas have been derived from everyday activities in the home, like the fuzzy ventilation system. It uses fuzzy logic to switch a fan on and off as dictated by its knowledge base of the amount of smoke, odors, and room temperature and humidity. The fuzzy bath, for example, has a controller that keeps the temperature of the water just right, not too hot and not too cold. If the water is lukewarm at first, it adds heat at a slower rate than if it's cold, avoiding wasteful overheating.

With the right fuzzy outlook, you could be the next to discover another innovative application of fuzzy logic.



OMRON and Fuzzy Logic

OMRON is renowned worldwide for its leading-edge fuzzy-logic technology research and applications. What has this technologically advanced company achieved and how? What does the future hold for this exciting fuzzy logic? Through an interview conducted in February 1991 with General Manager Masayuki Oyagi of OMRON's Fuzzy Technology Business Promotion Center, we hope to answer these questions.

How did OMRON become involved with fuzzy-logic technology?

In the early 1980s, we were fortunate enough to meet Assistant Professor Takeshi Yamakawa of Kumamoto University who specialized in this peculiar new technology known as "fuzzy logic." Our difficulties in control applications with conventional solutions, combined with his enthusiasm for fuzzy logic's abilities, led us to start studying it, but with only a few researchers. The late Executive Adviser Kazuma Tateisi (then Chairman), however, was most impressed with fuzzy logic and correctly predicted its importance. His encouragement led to the formation of the Fuzzy Project team, now the Fuzzy Technology Business Promotion Center, which conducts basic studies and explores new business opportunities.

OMRON's R&D efforts have given rise to numerous original applications for fuzzy logic. Could you give some examples?

The most obvious example would be the fuzzy controller, the first of its kind in the world. Developed in conjunction with Professor Yamakawa, this breakthrough was a huge sensation at every academic conference and fair it was exhibited at. Several varieties of fuzzy controllers are already on sale on the Japanese market. There are also fuzzy temperature controllers and fuzzy software development support tools to assist programmers.

To give some interesting applications, we developed a robot which can grasp something "pretty" soft and fragile—tofu (bean curd); and a can sorting machine capable of identifying cans by color. Overall, OMRON has more than 100 successful applications, 20 of which are now available to the public.

As 1991 progresses, you can expect more OMRON fuzzy logic-based products to be introduced. To date we have applied for more than 700 patents, a figure that gives some indication of OMRON's strength in fuzzy-logic applications.

Fuzzy-logic technology is obviously important to OMRON. What degree of importance does it have within the company?

In President Yoshio Tateisi's 1991 New Year address to OMRON employees, fuzzy logic was identified as one of our core technologies for the 1990s. By 1994, over 20% of our entire product line will include some form of fuzzy logic. Considering the diversity of OMRON's products, this is a challenging and significant goal.

OMRON's R&D investments account for approximately 7% of its total sales and I think fuzzy-logic research represents nearly 1%.

OMRON is not alone in the fuzzy-logic business. How does it distinguish itself from its competitors?

One of the main characteristics of OMRON's fuzzy logic-related business is the completeness of its product line. OMRON is presently the only company which provides an entire range of fuzzy-logic products, including digital and analog units, at virtually every speed, inference scale and computation capacity. OMRON also offers fuzzy-logic products in complete sets, including chips, software, and development tools, which can be used both in-house and by customers. Almost eight years of experience with fuzzy logic have gone into all of these products.

There are an amazing number of beneficial fuzzy-logic applications bearing OMRON's name, both original and joint customer development projects; the largest number in the world, I think. This success lets us continue to satisfy each customer's particular needs.

Aside from being a fascinating technology, what makes it so attractive?

OMRON doesn't think fuzzy logic itself makes products better. What is more important is the quality of user benefits that fuzzy logic can offer. Any business operates towards goals, such as major performance improvements, cost reductions, miniaturizing, or others. To attain these goals, businesses will usually refine their operations, generally without concern for the kind of technology used. But they do care about whether the technology can really work for them. Where existing computers function perfectly, such as for wage calculation, fuzzy logic has no value. However, with applications that are difficult or impossible using conventional technology, fuzzy logic may be the answer.

Where does fuzzy logic exhibit an improvement over previous technology?

The basic characteristic of fuzzy logic is that it can handle information with unclear boundaries, at any stage of input, processing, computation, memory or output. In other words, it can manage "fuzziness." The logic itself is purely mathematical, so the results are not "fuzzy" but rather very clear and precise.

Consider the can sorting machine which I mentioned earlier. With fuzzy logic, a computer can be instructed to sort cans according to their colors such as "reddish" or "bluish," instead of by reading characters printed on labels. Certainly character recognition technology for reading labels is very advanced, but when the can is turned so that the label isn't visible, it can't work. This is exactly where fuzzy logic is best.

What else is happening with fuzzy logic at OMRON? How many people are involved with this technology?

I'm not sure of the exact number but research on the technology itself in addition to developing applications involves many people. As an indication, at least 1,000 people have taken a fuzzy-logic seminar.

Some are members of the Laboratory for International Fuzzy Engineering Research (LIFE). One person from our Fuzzy Technology Business Promotion Center is now working at OMRON Advanced Systems, Inc. in Silicon Valley, studying American technology as well as introducing Japanese technology to the U.S. staff. We are also planning joint studies with various overseas manufacturers and seminars are held regularly, probably weekly, for both OMRON employees and our customers. Although most of these activities are within Japan, we plan to expand them to other countries this year.

The first product scheduled for marketing abroad in 1991 is the fuzzy temperature controller, to be introduced at the upcoming Hanover Fair. This will be followed by the fuzzy chip. OMRON will continue its marketing efforts overseas with fuzzy-logic products, ultimately aiming for simultaneous worldwide release. This coming spring, a fuzzy-logic product showroom will open at OMRON Electronics, Inc. in Schaumburg, Illinois.

That explains OMRON's aggressive marketing strategies. Some people say, however, that fuzzy logic in the U.S. and Europe is not as popular as in Japan, partially due to the term "fuzzy." What is your impression?

I think there are positive and negative feelings about this term. In its early days, "fuzzy" was not considered an academic term. Because of this, however, people got the impression that this technology was something quite singular which, I think, gave it more impact. On the down side, people thought that its results or ability would be "fuzzy," and questioned the product reliability.

Regardless of that, the fact is that fuzzy logic is used in very demanding areas, including nuclear power plants. In the U.S., NASA is working to implement fuzzy-logic control in space environments, an exceptionally difficult task. There are many energetic fuzzy-logic researchers in the U.S., Europe, and other places, which is a favorable change from earlier criticism of this unique technology. In fact, American trade magazines are constantly asking us for interviews, and French and German groups have been visiting OMRON regularly since 1989. This makes me confident that fuzzy-logic technology will grow rapidly in the both U.S. and Europe in the near future.

If consumer electronics giants such as GE introduce products with fuzzy logic, you may see a boom even larger than the one experienced in Japan last year. New technology that can handle things conventional machines cannot will naturally surprise and excite people, in any market and in any country.

1990 in Japan was considered the "year of fuzzy logic." What was OMRON's part in that and what are your comments on the boom?

With fuzzy logic, OMRON's goal is to raise the functions and capabilities of machines to levels comparable to human beings. In a sense, it can be considered "artificial intelligence" (AI). The left hemisphere of a human brain is used for logical processes, like reading and talking, while the right hemisphere is for intuitive and emotional mechanisms as well as unconscious information processing. Conventional computers imitate the left side, while fuzzy logic plays the role of the right side.

In chess, for instance, players make instant judgments, which would take many hours with a conventional computer. Such advanced thinking is the product of the cooperative efforts of both sides of the brain. We are imitating real life and are working on integrating conventional computers with fuzzy logic, expert systems, neural networks, and other technologies. OMRON's goal is to create machines that approximate human intelligence and capabilities, and yet still be compact and inexpensive.

The 1990 fuzzy-logic boom, I think, was the first wave which accurately reflected the direction of the technology and it motivated us to go further. The market's enthusiastic response was due to its sense that this long-awaited technology would create truly intelligent, user-friendly machines.

Main Events at OMRON Related to Fuzzy-logic Technology

1984 Research into fuzzy logic begun.

1986 Fuzzy-logic medical diagnosis system introduced.

1987 Assistant Professor Takeshi Yamakawa of Kumamoto University (now Professor of Kyushu Institute of Technology) introduces superhigh-speed fuzzy controller, test-manufactured by OMRON, at the 2nd Conference of the International Fuzzy Systems Association.

1988 World's first superhigh-speed fuzzy controller, FZ-1000, marketed.

OMRON participates in the establishment of Laboratory for International Fuzzy Engineering Research.

F (Fuzzy-logic technology research and marketing) project formed.

OMRON participates in the fuzzy-logic research project of the Science and Technology Agency.

Four working models of fuzzy-logic systems displayed at the international workshop on fuzzy-logic applications.

1989 Professor L.A. Zadeh welcomed to OMRON as senior advisor.

Ten new products using fuzzy-logic technology introduced, including chips, controllers, and software.

Fuzzy Technology Business Promotion Center established.

Bank note feeding mechanism using fuzzy logic developed for ATMs.

Fuzzy hybrid control method developed.

1990 "LUNA-FuzzyRON" fuzzy-logic software development support system developed.

Fuzzy-logic human body sensor developed.

Fuzzy controller-related gain adjustment method devised.

Failure diagnosis and prediction system for machine tools developed using fuzzy-logic expert system.

Fuzzy inference unit, C500-FZ001, marketed.

Two new series of digital fuzzy processors developed, FP-3000 series controllers and FP-5000 series multitask processors.

Development tools for the FP-3000 marketed.

Fuzzy inference molding machine support system developed.

Fuzzy temperature controller, E5AF, marketed.

Fuzzy-Logic Products

OMRON has released numerous innovative products that use fuzzy logic. A few of those products scheduled for release overseas are listed below:

FP-3000 Digital Fuzzy Processor-Controller
Cost-effective fuzzy chip ideal for control and simple pattern recognition.

* High-speed inference processing — 650μs/(5 antecedents and 2 consequents, 20 rules, 24MHz (external clock speed)).
* Bus interface similar to that of an SRAM allows connection to various CPUs.
* Fuzzy-logic operation can be accomplished on a single chip (Single mode).
* High 12-bit resolution.
* Up to 128 rules applicable for each inference (Expanded mode).

FS-10AT Fuzzy Software Tool
A personal computer software designed to create rules and membership functions for fuzzy inference.

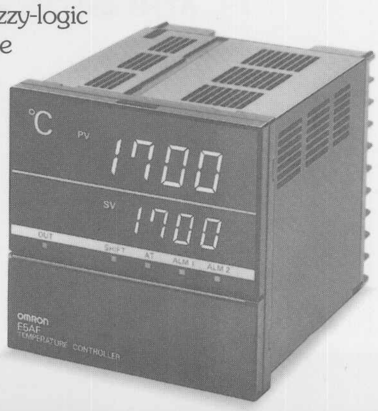
* Compatible with IBM PC-AT.
* Allows performance of trial control using A/D and D/A expansion boards.
* Outputs created rules and membership functions as object code for the FP-3000 fuzzy controller and FB-30AT fuzzy inference board.

FB-30AT Fuzzy Inference Board
FP-3000 chip-packaged board

* Can be inserted into an IBM PC-AT expansion slot.
* Uses the rules and membership functions created by the FS-10AT.
* Provided with driver software, allowing fuzzy inference to run with the user's software.
* Applications include evaluation and field tests of the FP-3000, and addition of fuzzy-logic functions to personal computers.

E5AF Fuzzy Temperature Controller
The industry's first temperature controller to employ fuzzy logic.

* Highly precise (±0.3% error) and fast response to external disturbance.
* Hybrid control integrates PID control and fuzzy-logic control to improve disturbance response significantly (50% higher than conventional PID control).
* Easy operation—similar to that of conventional models.
* Automatic fuzzy-logic parameter setting. Fuzzy-logic parameters can be programmed to fit the application.
* Ideal for use in physical/chemical equipment, industrial furnaces, and semiconductor manufacturing equipment.



Fuzzy-Logic Technologies

OMRON is also involved in regular development of practical fuzzy-logic applications. Here are some examples:

Fuzzy-logic Failure Diagnosis and Prediction System for Machine Tools

In a joint development with Komatsu Ltd., this system generates and displays various machine failure predictions in order of probability, enabling a much simpler detection of the real cause of the fault. It will reduce servicing time by 24%, and software development time to 1/5 of conventional systems.

Fuzzy Inference Molding Machine Support System

This system uses fuzzy inference to automatically remedy the conditions that cause plastic molding failures. Unlike conventional systems which call for expert attention, this new system only needs a simple defects input into the built-in controller. Fuzzy inference, with its expert knowledge base, takes care of the rest automatically, and at the same level of competence as a specialist.

Bank Note Feeding System Employing Fuzzy Logic for ATMs and CDs

The texture and quality of bank notes stored in automatic teller machines (ATMs) and cash dispensers (CDs) are easily affected by ambient humidity, conveyance conditions, etc., which in turn makes stable bank note feeding difficult. With the aid of fuzzy logic, this new mechanism keeps the gap between the rollers at the optimum level, notably increasing the reliability of ATMs and CDs as well as reducing the need for maintenance.

OMRON Corporation

Head Office: Karasuma Nanajo, Shimogyo-ku, Kyoto 600 Japan
Tokyo Head Office: 4-10, Toranomon 3-chome, Minato-ku, Tokyo 105 Japan